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14. ABSTRACT
The spring of 2000, a proposal was submitted to Mr. Ken Dial at the Office of Naval Research (ONR) to study a novel approach of time-reversed acoustics to detect targets buried in a littoral environment. The proposal was written by Dr. Thomas Drake, currently at ONR, and David Pierson, currently at John Hopkins University Applied Physics Laboratory (APL), under the advice of Dr. Tony Clark, currently at North Carolina State University (NCSU) and completed under the guidance of Dr. David Aspnes, currently at NCSU. The research demonstrated through theoretical calculations and computer simulations that time-reversed acoustics can be used to detect and classify a target buried in a inhomogeneous environment using acoustic transceiver of a simple geometrv.

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Final Report on "Buried Target Detection Using Time-Reversed Acoustics"

David Pierson

06/02/04

Abstract

The spring of 2000 a proposal was submitted to Mr. Ken Dial at the Office of Naval Research (ONR) to study a novel approach of time-reversed acoustics to detect targets buried in a littoral environment. The proposal was written by Dr. Thomas Drake, currently at ONR, and David Pierson, currently at Johns Hopkins University Applied Physics Laboratory (APL), under the advice of Dr. Tony Clark, currently at North Carolina State University (NCSU) and completed under the guidance of Dr. David Aspnes, currently at NCSU. The research demonstrated through theoretical calculations and computer simulations that time-reversed acoustics can be used to detect and classify a target buried in an inhomogeneous environment using an acoustic transceiver of a simple geometry.

Research

The process of time-reversal is conceptually simple, imagine a playing a movie of a still pond perturbed by a single drop in reverse order. The result would be to return the movie to the original state of the pond with the wavefronts converging to the source. This is the result of the spatio-temporal symmetry of waves, despite that time propagates in the forward direction, it is possible to have a wave propagate back to the source by transmitting a recorded wave in reverse temporal order. Indeed, the research into the acoustical version of this phenomenon has been studied by several groups for uses ranging from medical imaging to underwater communications to location of barrels buried in a landfill, all using a geometry of a time-reversal mirror that involves an active acoustic source and an array of active transceivers to transmit the time-reversed signal they record. Pierson proposed that it is possible to use time reversal involving only a single transceiver to detect a target that is acoustically different from the surrounding inhomogeneous environment, and be able to detect this target when the transceiver is located in a different medium than that of the target.

To facilitate the research, Pierson contacted Dr. Eric Pouliquen, currently at SACLANTCEN, for the model they developed to study the acoustical properties of sediments. Pierson modified the model to include a spherical target of known diameter and acoustical properties at a set location, then he performed simulations modeling two different sediments and a variety of initial pulses. The results showed the following behavior of the time-reversed signal:

1. The time-reversed signal converges to a single waveform that is dependent on the the sphere radius.
2. The waveform has a dependency on the sediment composition of the sediment and the sphere.

3. There is a dependency on the recording start time and duration of recording to the effectiveness of the time-reversal procedure.
4. The converging waveform is dependent on the initial probe pulse ability to detect the sphere. The amount of detection is within theoretical noise boundaries of sonar systems, thus demonstrating that time-reversal can be used as a method of detection where other methods may not detect any target.

After the defense of Pierson's dissertation, under the advisement of Dr. Aspnes, he demonstrated that time-reversal is not a necessary to detect buried objects. Instead by simply transmitting a judiciously chosen subset of the recorded signal without using time reversal, the sphere can be detected at a much lower threshold than that using time reversal. Through theoretical analysis, Pierson demonstrated that time-reversal is a specialized subset of autocorrelation of signals and that what enables this process, both time reversal and non-time reversal, to detect the sphere is the high frequency components of the backscattered being retransmitted. These components have been tuned so that only the frequencies that can propagate through the inhomogeneous environment of the sphere are used to enhance the return from the sphere. The implications of this final work are far reaching and require a more involved study both theoretically and experimentally.